4-1987

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Published in Palaios, Apr 1987; 2: 158 - 164.

Diatoms and Tonsteins as Paleoenvironmental and Paleodepositional Indicators in a Miocene Coal Bed, Costa Rica

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PALAIOS, 1987, V. 2, p. 158–164

Fresh-water diatoms are present in coal, and tonsteins (altered volcanic ash) are interbedded with the coal, in the Miocene Venado Formation on the southwest margin of the Limon Basin, in Provincia Alajuela, northern Costa Rica. The Venado Formation is composed of more than 300 m of mudstone, siltstone, sandstone, limestone, volcaniclastics, and coal beds. The coal beds are of unknown lateral extent and mainly occur in the middle part of the formation. The Pataste coal bed occurs near the middle of the formation and is divided into three parts by two tonstein layers. The abundance of biogenic opaline material (diatoms) in the coal is believed to be a direct response to an influx of silica from volcanic tuffs that later altered to the tonsteins.

Diatoms are a useful microscopic tool for identifying the depositional environments of the Pataste coal deposit. The diatoms identified include Aulacosira ambigua, Pinnularia sp., Eunotia *spp., and* Achnanthes exigua, *among others. The abundance of* Aulacosira ambigua *suggests that an open-water lacustrine environment was present locally.* Achnanthes exigua *and the remaining diatom species are benthic forms that lived in shallow fresh-water to slightly acidic swamp environments. The different types of diatoms found in the coal indicate that swamp environments were intermixed with lacustrine environments during the formation of the peat deposit or that the coal records environmental changes through time.*

INTRODUCTION

The Venado area encompasses about 286 km^2 in the northwest part of Costa Rica north of the Arenal Volcano, and northeast of Lake Arenal (Fig. 1). Monterrey, the largest settlement in the area, has a population of more than 500. Most of the land surface in the region had extensive forest cover, but has been cleared to graze cattle. Remaining forests are confined to steep slopes adjacent to numerous streams.

Samples of coal were collected from outcrops along streams. The samples were submitted for geochemical analysis, and the results have been published (Coates and Sanchez, 1984; Sanchez et al., 1985; Landis et al., 1983). Analyses of four channel samples of coal and impure coal show a range of 3508 to 5445 BTU/lb, 0.3–3.0 percent sulfur, and 4–46 percent ash on an as-received basis (Coates and Sanchez, 1984).

The whole coal was initially examined in a scanning electron microscope equipped with an X-ray analyzer attachment. Further examination of the diatoms in the coal required additional preparation to separate the diatoms. The coal was boiled in nitric acid and rinsed in distilled water. The samples were then mounted on stubs, plasma coated wtih gold-palladium alloy, and viewed by the scanning electron microscope.

Regional Structure and Deposition

Costa Rica and much of Central America lie on the trailing edge of the Caribbean tectonic plate (Fig. 2) in an area strongly influenced by volcanism and coastal marine sedimentation. The Venado Formation probably represents a molasse deposit, which has been defined as "a paralic (partly marine, partly continental or deltaic) sedimentary facies consisting of a very thick sequence of soft, ungraded, cross-bedded, fossiliferous conglomerates, sandstones, shales, and marls, characterized by sedimentary structures and sometimes by coal and carbonate deposits . . . A molasse deposit is a result of the wearing down of elevated mountain ranges and immediately succeeds the main paroxysmal (diastrophic) phase of orogeney" (Bates and Jackson, 1980). The elevated mountain ranges in this definition are represented by the Middle America Deformed Belt (Fig. 2), which was active in Costa Rica during Miocene time.

Stratigraphy

The Venado study area is located near the western edge of a topographic and structural depression known as the Limon Basin (Fig. 1). Outcrops in the Limon Basin consist mostly of middle Tertiary marine rocks. Overlying the marine rocks is a sequence of Miocene rocks composed of very fine grained to very coarse grained clastics, volcaniclastics, and coal beds. The coal-bearing part of the Miocene sequence is assigned to the

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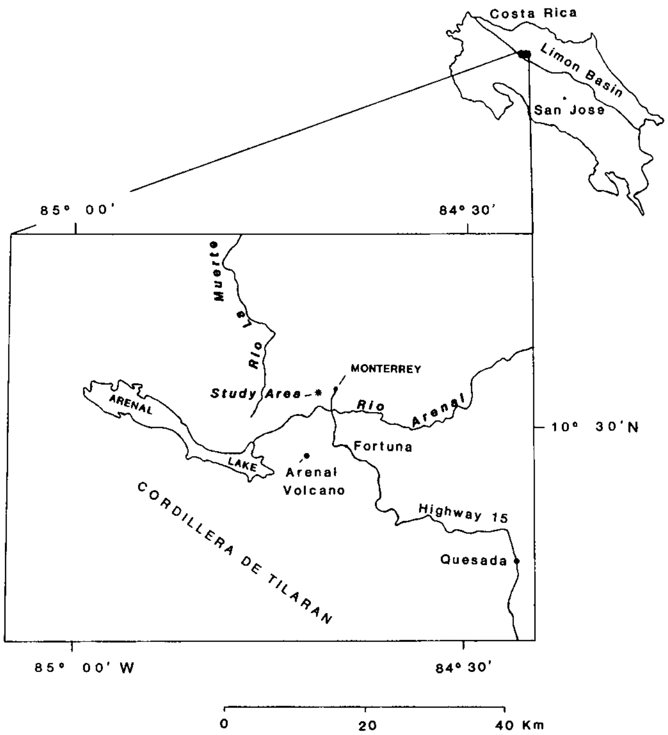

FIGURE 1—Location map of the study area in northern Costa Rica.

Venado Formation, which crops out on the northeast flank of the Cordillera de Tilaran in the northwestern part of the Limon Basin. The Venado Formation consists of more than 300 m of interbedded mudstone, siltstone, sandstone, marine limestone, volcaniclastics, and coal.

Pataste Coal Bed

The coal bed studied is informally known as the Pataste bed and crops out in the middle part of the Miocene Venado Formation (Weyl, 1980), southwest of the town of Monterrey. The bed (Fig. 3) consists of a lower part (A), which is 1.3 m thick, and middle (B) and upper (C) parts that are each 0.7 m thick. The lower and middle parts are separated by a tonstein (altered volcanic ash) 0.2 m thick. The middle (B) and upper (C) parts of the coal bed are separated by a second tonstein 0.15 m thick.

FRESHWATER DIATOMS IN THE PATASTE COAL BED

The Pataste coal bed contains freshwater diatoms; *Aulacosira ambigua* and *Achnanthes exigua* are the dominant forms present (Fig. 4A,B).

Aulacosira ambigua is a planktonic diatom that lives in the open-water regions of ponds and lakes where it is suspended by turbulence in the photic zone, whereas *Achnanthes exigua* is a benthic diatom that lives attached to underwater substrates such as plant stems, wood, or rocks. Because it must photo-

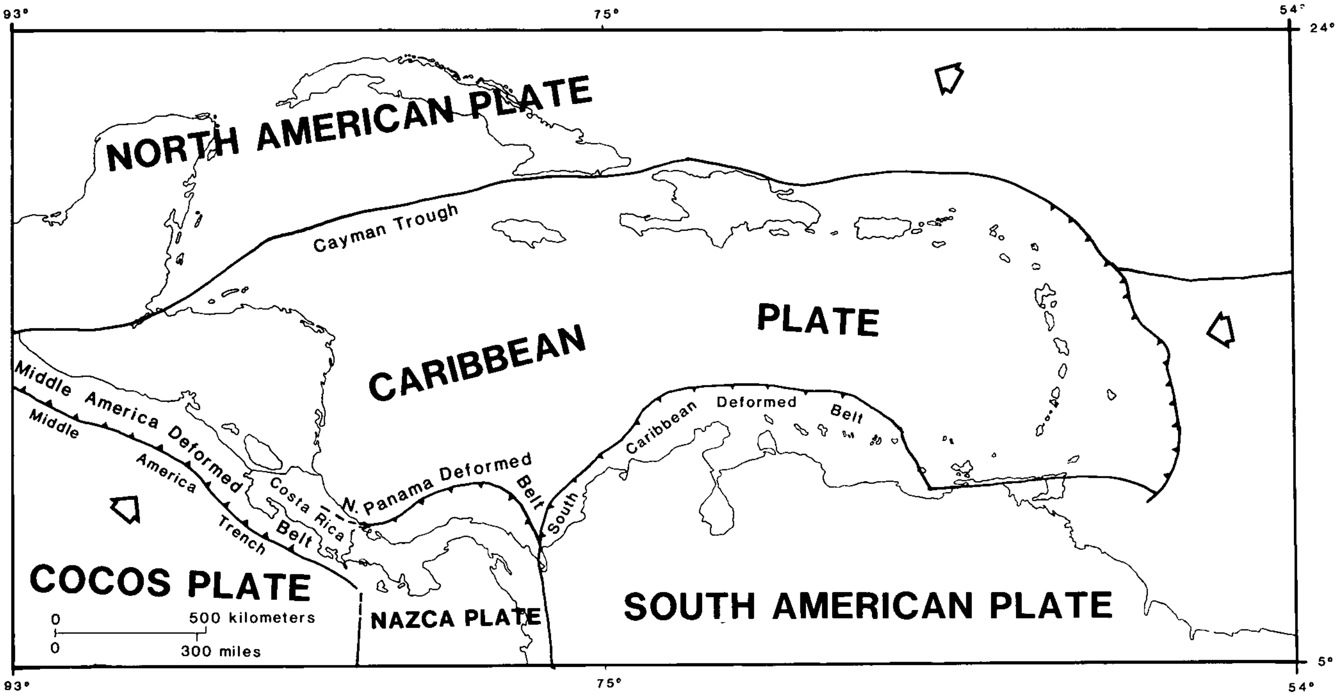

FIGURE 2—Map of Caribbean Region showing plates and plate boundaries (modified from Case and Holcombe, 1980).

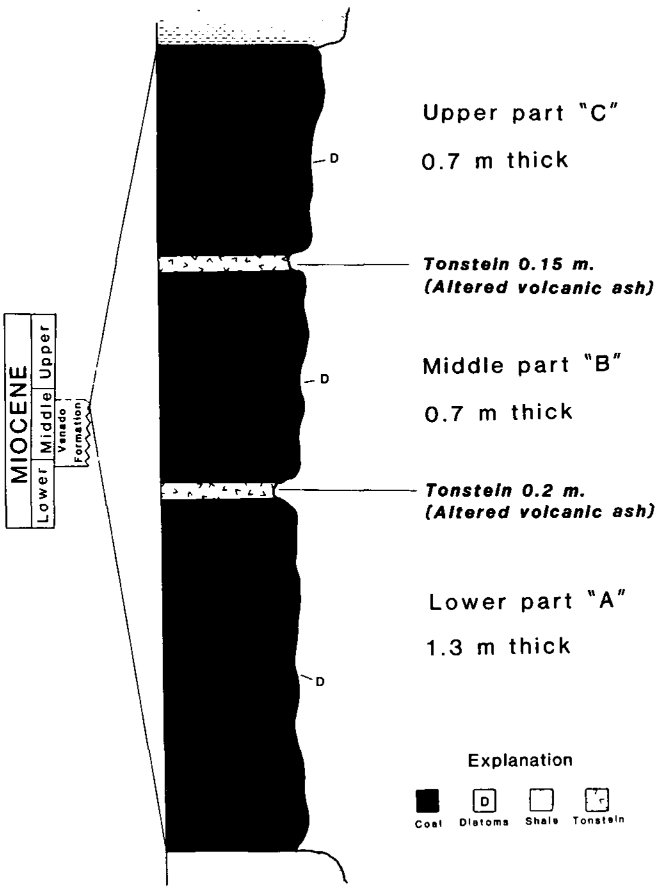

FIGURE 3—Diagrammatic section of the Pataste coal bed.

synthesize, *Achnanthes exigua* is restricted to shallow water where light penetrates to the bottom. Both diatoms are characteristic of fresh, slightly alkaline, oxygen-rich water. These diatoms are major components of the modern algal flora of Lake Olomega on the southern coastal plain of El Salvador, Departamento de San Miguel, and this locality might represent a partial analog to the aquatic environments present during the time of deposition of the Pataste coal bed.

At the time of collection (Table 1), the conductivity of Lake Olomega was 280 millimhos/cm. The lake is roughly oval in shape and approximately 7 × 5 km in dimension. It has a large littoral area and a maximum depth of about 2.5 meters. Analyses by Armitage (1957) indicate that water level and lake chemistry fluctuate according to seasonal precipitation that occurs principally during the winter.

Cymbella minuta (Fig. 4C), *Fragilaria pinnata* (Fig. 4D), *Pinnularia* sp. (Fig. 4E), *Navicula pupula* (Fig. 4F), and *Eunotia flexuosa* (Fig. 4G) are represented in smaller numbers in the Pataste coal bed. Collectively, the presence of these species implies shallow fresh-water conditions, but *Pinnularia* and *Eunotia* also suggest moderately acidic swamp conditions.

The variable lacustrine and swamp conditions represented by the diatoms indicate either that the coal was deposited in mixed depositional environments, or that the coal records environmental changes through time.

TABLE 1—Chemical analysis of Lake Olomega, El Salvador, on November 16, 1967. All analyses are in mg/L.

16 XI 1967 (mg/L)			
Na	30	HCO_3	175
Ca	16	SO_4	8
Mg	11	Cl	17
K	13		

TONSTEINS IN THE PATASTE COAL BED

Tonsteins are compact argillaceous rocks composed mostly of various forms of the clay mineral kaolinite with occasional detrital and carbonaceous material. They are commonly found as thin, widespread partings within coal beds. As defined in studies of these partings in the Western Interior of the United States, tonsteins are volcanic ash falls that have been altered to clay minerals (Bohor et al., 1976; Ryer et al., 1980). The Pataste coal bed contains two of these tonsteins (Fig. 3).

Scanning electron microscope (SEM) photographs (Fig. 5A–C) show grains of the minerals hypersthene (pyroxene) and plagioclase feldspar, as well as a kaolinite vermicule, in the tonsteins of the Pataste coal bed. In addition to the hypersthene and plagioclase shown, small amounts of quartz, biotite, zircon, and magnetite are also present in the tonsteins. Volcanic glass that formed most of the original ash has been altered to kaolinite (Fig. 5C), releasing silica ions into solution. The presence of hypersthene and calcic plagioclase feldspar, with only small amounts of primary quartz, indicates that these former ash beds were derived from an intermediate andesitic magma, common to island arc volcanism. Tonsteins from other coal beds in the Venado Formation contain relatively more abundant quartz and were probably derived from slightly more silicic magmas.

A tonstein can be mineralogically fingerprinted, meaning it can be specifically characterized as to origin and mode of diagenesis if a distinct suite of minerals can be identified within it. The number and arrangement of tonstein partings also help to identify particular coal beds (Ryer et al., 1980). For example, a coal bed with a pair (doublet) of tonsteins can be compared and tentatively correlated with other coal beds having similar paired tonsteins. Because the volcanic ash precursors of tonsteins are isochronous over their entire lateral extent, the degree of certainty that the coal beds containing these doublets correlate exactly increases greatly if the suites of minerals between pairs of tonstein can be shown to match each other.

PALEODEPOSITIONAL RECONSTRUCTIONS

Little information is available concerning the paleogeography of the Venado Formation. Outcrops in the study area are poor and difficult to correlate. Nonetheless, we observed a variety of

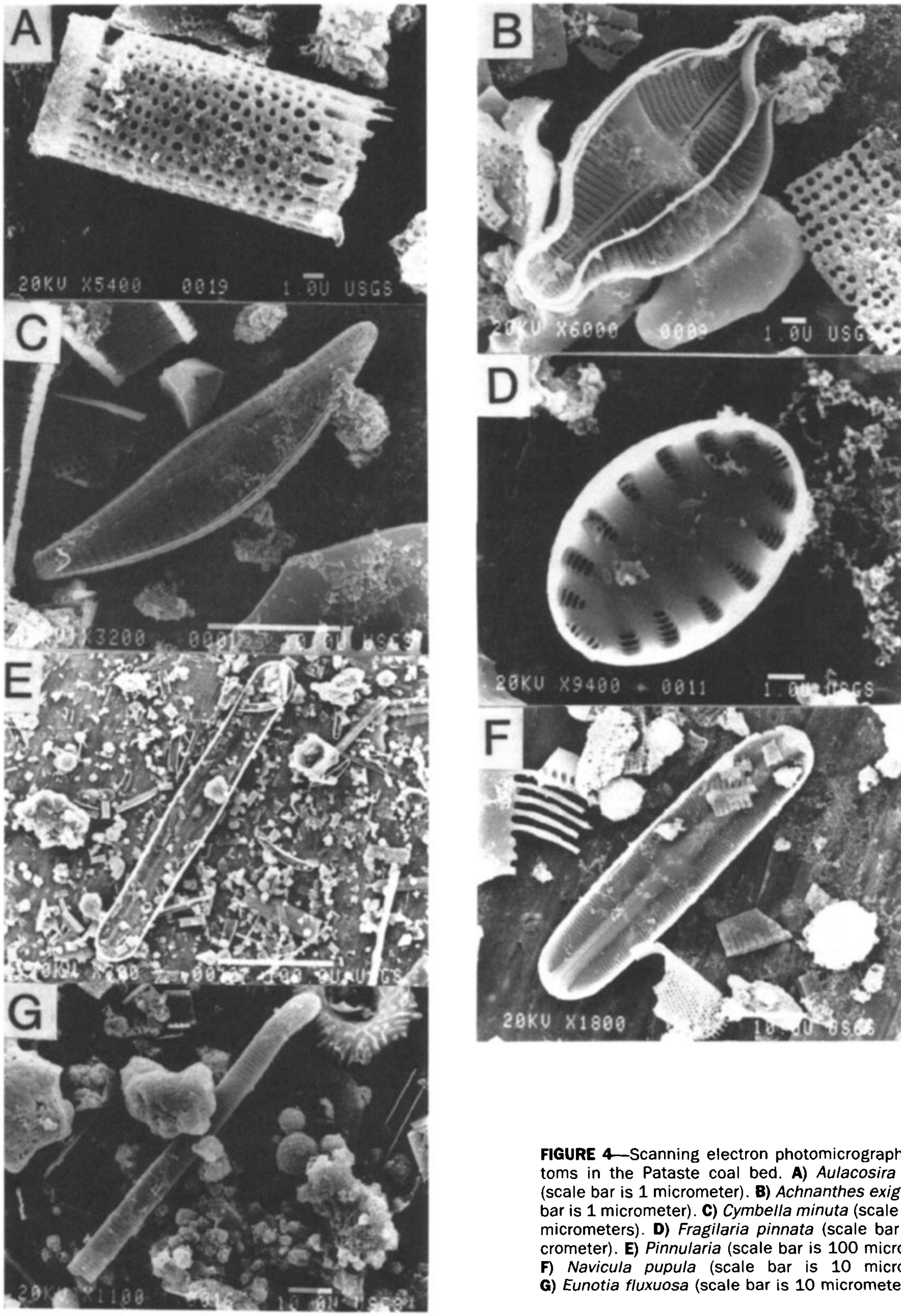

FIGURE 4—Scanning electron photomicrographs of diatoms in the Pataste coal bed. **A)** *Aulacosira ambigua* (scale bar is 1 micrometer). **B)** *Achnanthes exigua* (scale bar is 1 micrometer). **C)** *Cymbella minuta* (scale bar is 10 micrometers). **D)** *Fragilaria pinnata* (scale bar is 1 micrometer). **E)** *Pinnularia* (scale bar is 100 micrometers). **F)** *Navicula pupula* (scale bar is 10 micrometers). **G)** *Eunotia fluxuosa* (scale bar is 10 micrometers).

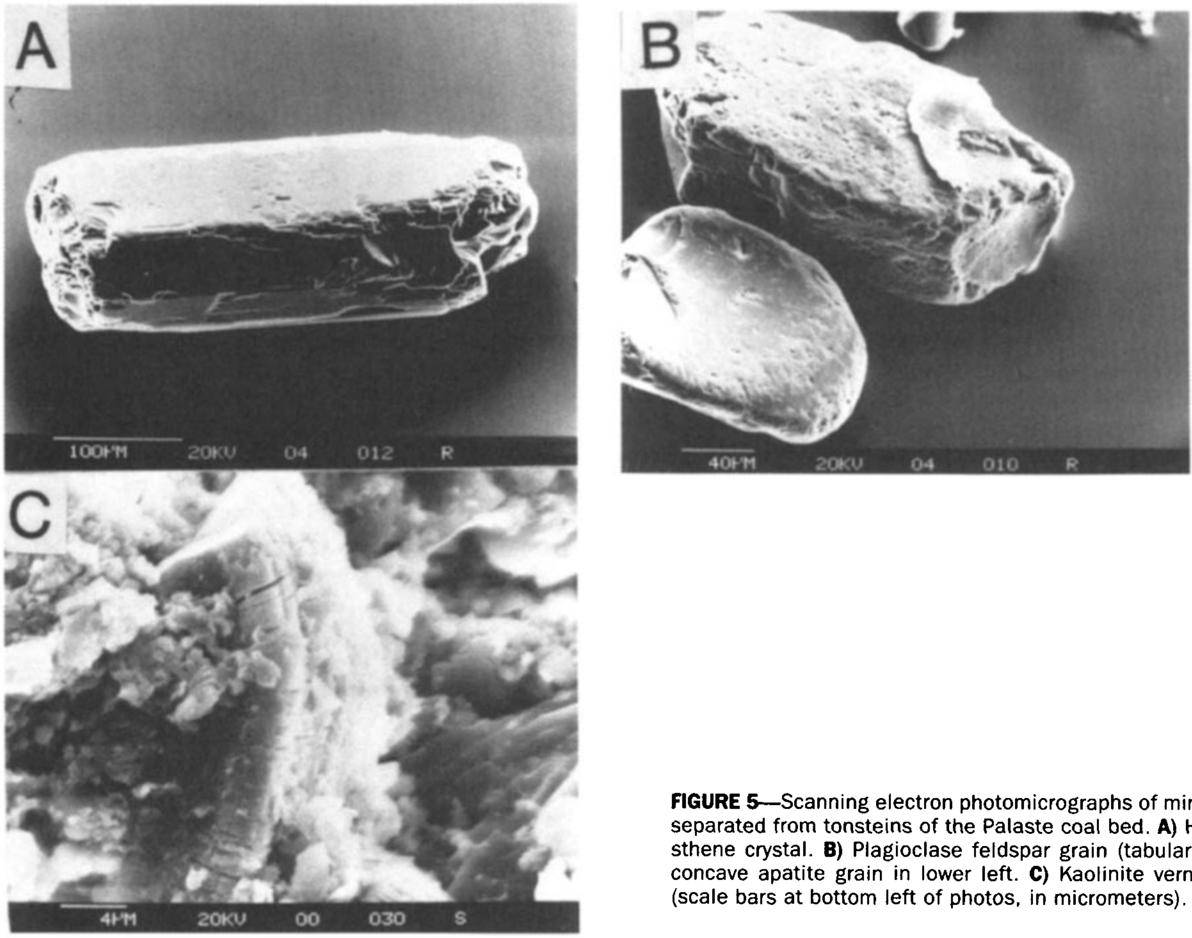

FIGURE 5—Scanning electron photomicrographs of minerals separated from tonsteins of the Palaste coal bed. **A)** Hypersthene crystal. **B)** Plagioclase feldspar grain (tabular) with concave apatite grain in lower left. **C)** Kaolinite vermicule (scale bars at bottom left of photos, in micrometers).

facies that could be identified by sedimentary structures, vertical textural changes, mineralogical variation, and fossil content. These data were used to reconstruct paleodepositional environments (Fig. 6).

Swamp Facies

The diatoms and tonsteins in the coal beds, along with sedimentary structures in the sandstones, siltstones, and shales above and below the coal bed, indicate a mixture of depositional subenvironments in the swamp facies. The diatoms indicate that a fluvial and/or lacustrine environment existed concurrently with the swamp. The tonsteins indicate a period of intense volcanic activity that produced an ash fall that covered the swamp and destroyed much of the biota.

Marine-Nonmarine Facies

Vertical sequences of intertonguing marine limestones and continental deposits (fluvial sandstones, shales, and coal) indicate that nearby seas were transgressing and regressing. Marine fossils (pectins) found in limestones of the Rio La Muerte area (north-central part of the study area) indicate that marine environments were present in the study area. The limestones in this area are also overlain by tuffaceous sandstones. Together these deposits imply changing environments during the deposition of the Venado Formation.

Volcanic Facies

This facies is best illustrated in the Rio la Muerte area, where a 40-meter-thick ignimbrite (pyroclastic flow) deposit is overlain and underlain by nonmarine fluvial sandstone, siltstone, and coal beds. The presence of the ignimbrite demonstrates that volcanism was concurrent with the deposition of the nonmarine sediments in the study area. Because the coal deposits contain tonstein partings, volcanism also was occurring during the deposition of the Venado sediments.

Lagoonal Facies

The lagoonal facies is represented by the dark-gray siltstone and fine-grained sandstone deposits of the Venado Formation. This facies contains brackish-water fauna (oysters and gastropods) in the Rio de la Muerte area. This deposit indicates that sea waters entered the area through a tidal inlet, estuary, or some other type of coastal opening.

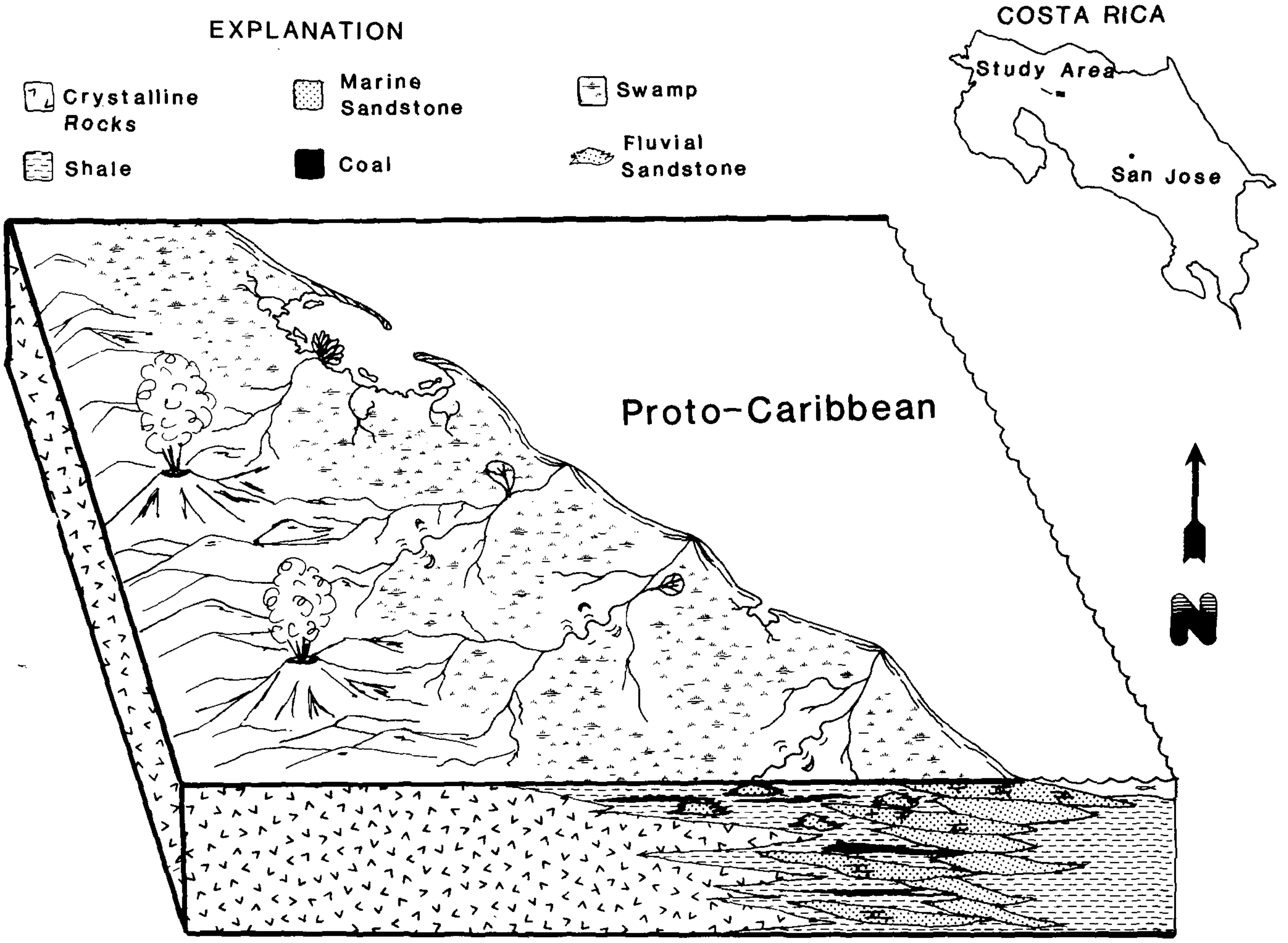

FIGURE 6—*Miocene paleodepositional environment, Venado coal area, Costa Rica.*

Modern Analogs for Diatom Deposition

Holocene analogs for the diatoms (algae) in the Venado coal deposits are common in other parts of the world. For example, during drought periods in the Everglades of Florida, fires can burn and destroy large areas of peat deposits. Lakes form in the depressions left behind as the peat burned, providing habitats for algae and other fresh-water flora and fauna. These algae theoretically can be preserved in the peat deposits if given the correct postburial and diagenetic conditions. A similar habitat and depositional history are postulated for the diatoms in the Pataste coal bed.

The environment today in Costa Rica is probably much the same as it was during the Miocene. Large volcanos exist close to the Limon Basin, which also contains Holocene peat deposits. Recent volcanic activity has deposited layers of ash on top of the peat deposits (Cohen and Raymond, 1984). The volcanic deposits have influenced the peat geochemistry by infusions of silica, which may have encouraged the growth of diatoms also present in these deposits.

Depositional Model for the Venado Area

A paleoenvironmental-paleodepositional model, Figure 6, hypothetically illustrates conditions in the Venado area during Miocene time. The model attempts to illustrate the vertical and lateral relationships of the different facies of the Venado Formation. Detailed drilling and mapping will provide additional information and will allow an evaluation of the accuracy of the model.

CONCLUSIONS

Diatoms are a useful microscopic tool for identifying the depositional environments of the Pataste coal deposit. The different types of diatoms found in the coal indicate that swamp environments were intermixed with lacustrine environments. The formation of lakes in a swamp environment and introduction of algae into the swamp during the time of peat deposition can be explained by climatic factors. Drought conditions during peat deposition may have caused the peat to become dry enough to burn. Even mild drought conditions during peat deposition may have caused the surface of the peat to dry out. Lightning from thunderstorms could then have ignited the dried peat, and where the peat was destroyed, small lakes may have formed in the depressions. Algae could then be introduced into the peat-forming environment and later be preserved in the resulting coal bed.

Tonsteins in the Pataste coal bed indicate that volcanism was concurrent with peat deposition. A unique suite of minerals in the tonsteins may help to identify and correlate the resulting coal bed. The number and arrangement of tonsteins also help to identify particular coal beds. The origin of the tonsteins is attributed to volcanic ash falls that altered to clay minerals in an acidic swamp environment, releasing silica into solution. The influx of silica from the altering ash may have caused a "bloom" of siliceous algae (diatoms) to occur in the swamp waters (Edmondson, 1984; Taliaferro, 1933).

The paleodepositional model presented here is considered a preliminary step in explaining the geology of the Venado area. The model can be used to delineate the areal distribution of coal beds and their associated sedimentary rock units by employing tonsteins to correlate specific coal beds and by using the diatoms for recognizing and correlating paleoenvironmental zones within the coal deposits. The resulting correlations can also help the exploration geoscientist select target areas for future drilling programs, and expedite a coal exploration program.

ACKNOWLEDGMENTS

This report benefited from critical reviews by Henry W. Roehler, Morris W. Green, and John W. M'Gonigle. Kathryn Dieterich-Rurup prepared and photographed the coal samples.

This study resulted from work conducted as part of a cooperative program between the U.S. Geological Survey and the Refinadora Costarricense de Petroleo, S. A., and funded by the United States Agency for International Development. Special thanks to Edwin R. Landis for arranging the cooperative program that made this study possible.

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You can know when a theory has arrived when people start claiming they had the idea first.

—Mott T. Greene